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Review of freshwater turtle ecology and flow

Literature review

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Cover image: An Eastern long-necked turtle caught recorded on an underwater video camera by Daniel Coleman

Summary

New South Wales is home to seven native species of freshwater turtle, including two that are endemic to the State. Turtles carry out critical ecosystem functions, but their numbers are declining globally. In NSW, three species are currently listed as endangered (the Bell's turtle, *Myuchelys bellii,* and the Manning River turtle, *Myuchelys purvisi*) or critically endangered (the Bellinger River turtle, *Myuchelys georgesi*).

River regulation and water extraction has altered the natural flow regime of the State's rivers, but the impacts of these changes on freshwater turtles are not well understood. A key objective of the NSW *Water Management Act 2000* is to protect, enhance and restore river ecosystems, ecological functions and biodiversity. To protect NSW's freshwater turtle species, it is critical that water managers understand the potential impacts of changes in flow on turtle ecology.

We have used the available literature to identify the links between river flow and key ecological attributes of the State's freshwater turtle species. There is substantial evidence that changes in flow influence turtle habitat suitability, reproduction and recruitment, food resources and movement, with potential implications for turtle abundance, distribution, body condition, and individual and species survival.

Based on these findings, it can be inferred that changes to the natural flow regime due to water use and regulation impact freshwater turtles. Endangered species may be most vulnerable to the impacts of these changes.

Potential impacts of water use and regulation on freshwater turtles

Based on the known relationships between NSW's freshwater turtle species and flow, water use and regulation are likely to impact turtles through the following mechanisms:

1. **Extraction from pools may reduce pool volume and depth, reducing refuge habitat**

   Species likely to be affected: *M. belli, M. purvisi, M. georgesi* and *M. latisternum*

2. **Extraction from running river waters during low flows may reduce riffle and shallow pool edge foraging habitat**

   Species likely to be affected: *M. belli, M. purvisi, M. georgesi, M. latisternum*

3. **Extraction from running river waters may increase the frequency and duration of low flows, potentially impacting aquatic respiration, reproduction and recruitment, and access to food resources**

   Species likely to be affected*:* *M. belli, M. purvisi, M. georgesi, M. latisternum*

4. **Regulating infrastructure and extraction from running river waters may limit turtle movement by reducing longitudinal connectivity and lateral connectivity with temporary habitat**

   Species likely to be affected by reduced longitudinal connectivity: species that travel primarily through water with little overland movement (i.e. all but the eastern long-necked turtle, *C. longicollis*)

   Species likely to be affected by reduced lateral connectivity: *C. longicollis*

5. **Regulating infrastructure may increase the risk of nest inundation, impact access to food resources, impact water temperatures and change turtle behaviour**

   Species likely to be affected: all species potentially affected.

Next steps

It is evident that freshwater turtle ecology is linked to flow and as such, changes in flow regimes due to water use and regulation are likely to impact turtles in NSW. However, there is still uncertainty about the direct causal links between flow and turtle ecological attributes. This is a major knowledge gap that requires direct evaluation to ensure the appropriate management of flows to protect freshwater turtles.

To address this knowledge gap, we recommend:

a) Surveying of water sources using, trapping techniques, baited remote underwater videos (BRUVs), and visual observations to provide estimates of species relative abundance and occupancy, improving the availability of turtle distribution data. eDNA could provide a complimentary technique to map turtle distributions.
b) Assessment of the usage of shallow pool edge and riffle habitat by select species using radio-tagging. This assessment should focus on water sources where both water extraction and these species are known to occur.
c) Investigation of the likelihood of nest flooding within and downstream of artificial storages, considering historical flow records, species distribution and known nesting behaviour.
d) Further research on the relationship between flow and habitat preference, food resources, reproduction, recruitment and movement for all species is still required.
e) Seeking opportunities to collaborate with other NSW freshwater turtle management programs and research institutions to better understand turtle-flow relationships and enable the better management of flows to protect freshwater turtles in NSW.

Contents

Introduction

New South Wales is home to seven native species of freshwater turtle (Figure 1; Table 1) (DPE, 2018). Two of these species – the Manning River turtle, *Myuchelys purvisi,* and the Bellinger River turtle, *Myuchelys georgesi* – are endemic to the State. Turtles play an important role in global ecosystems, carrying out critical functions in food webs, energy and nutrient cycling, vegetation dispersal and water quality maintenance (Lovich et al., 2018). Freshwater turtles are also culturally significant to Australian Indigenous people (Howard et al., 2011).

Turtle populations are declining globally – more than half of the world's 356 recognised species are threatened or have become extinct in modern times (Lovich et al., 2018). Of NSW's seven freshwater species, the Manning River turtle, Bellinger River turtle and the Bell's turtle, *Myuchelys bellii*, are currently listed as vulnerable, endangered or critically endangered in NSW (listed under the *Biodiversity Conservation Act 2016)*, in Australia (listed under the *Environment Protection and Biodiversity Conservation Act 1999)* or both. Declining populations of the broad-shelled turtle, *Chelodina expansa*, the eastern long-necked turtle, *Chelodina longicollis*, and the Murray River turtle, *Emydura macquarii*, have also been reported (Chessman, 2011; Van Dyke et al., 2019).

Threats to freshwater turtles include predation by invasive species (such as the red fox), hybridisation and competition with introduced turtle species, and novel diseases (summarised in

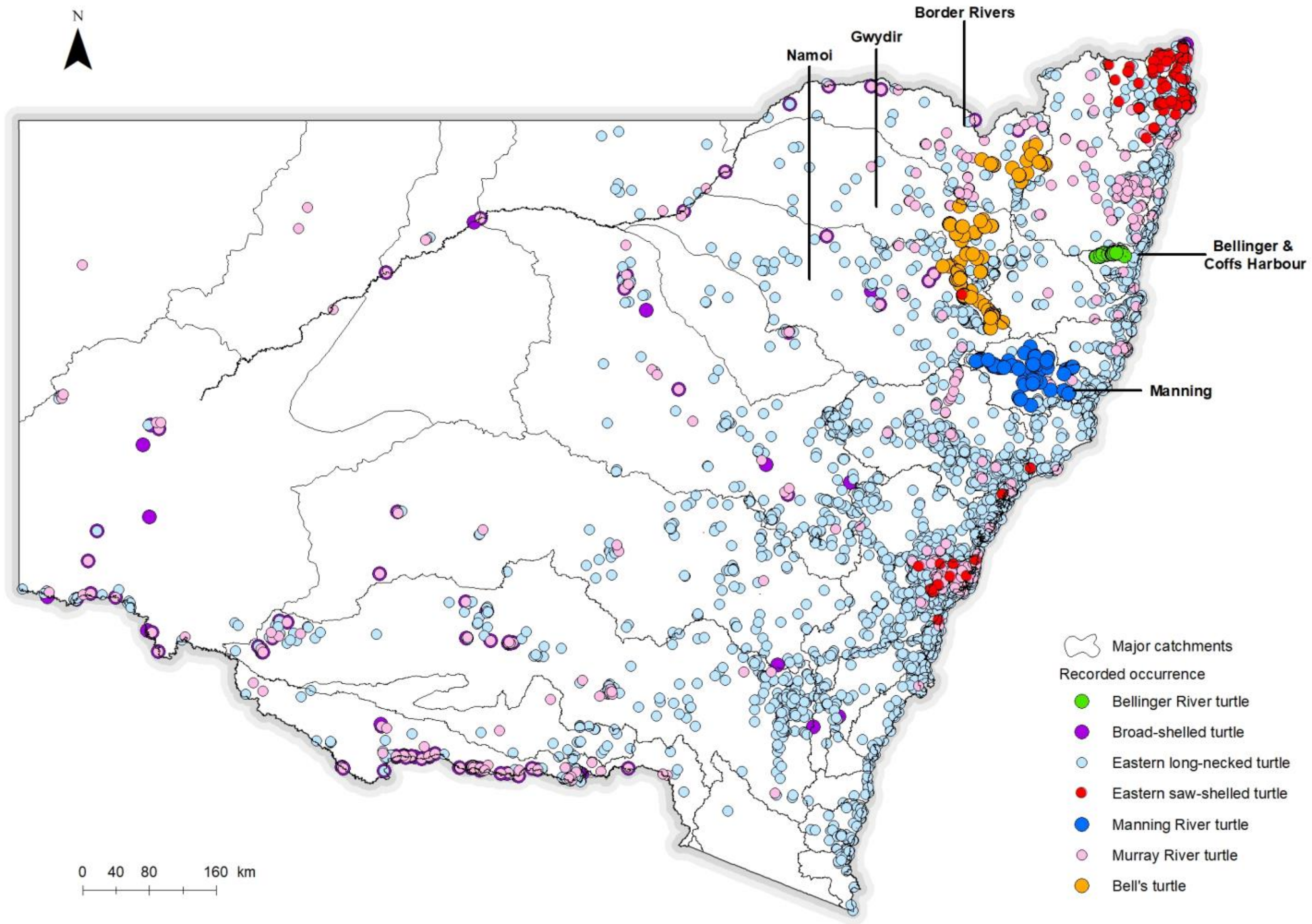

Figure 1 Map of freshwater turtle distribution in New South Wales (records sourced from bionet.nsw.gov.au)

Van Dyke et al., 2019). Urbanisation of river ecosystems has led to additional risks, including high road mortality, drowning in fishing nets and other human structures, removal of riparian vegetation and altered river geomorphology through damming and channelization (summarised in Hill & Vodopich, 2013; Van Dyke et al., 2019). Finally, changes to river flows may pose threats to freshwater turtles in NSW. The extraction of water and building of infrastructure like dams and weirs has altered the natural flow regime of the State's rivers, decreasing the overall flow volume, reducing flow variability, increasing drying rates and reducing connectivity between rivers and their anabranches, wetlands and floodplains (MDBA, 2018).

Flooding, extended dry conditions and reduced connectivity are all known to have negative impacts on freshwater turtles (Bodie, 2001; Chessman, 2011; Howard et al., 2011). Changes to salinity, sedimentation, turbidity and water temperature, which can result from altered flow regimes and river infrastructure, can also impact the health and reproductive output of turtles (Allanson & Georges, 1999; Ashton et al., 2011; Bower, Death, et al., 2012; Petrov et al., 2018; Reese & Welsh, 1998; Rolls et al., 2012; Spencer et al., 2007, 2014). Additionally, the presence of dams and weirs can limit turtle movement and result in physical injury and death when sudden water releases force turtles out of concrete release chambers or over weir walls (Hamann et al., 2007).

In NSW, water is managed under the *Water Management Act 2000*[1]. A key object of the Act is to protect, enhance and restore water sources, including their associated ecosystems, ecological processes and biological diversity. To meet this objective in relation to the protection of the State's freshwater turtles, it is critical that water managers understand the potential impacts of water regulation and extraction, and subsequent changes in river flow and ecosystem condition, on turtle species. We have reviewed the literature linking changes in flow with turtle ecology for the freshwater turtle species that inhabit NSW. Specifically, we have examined literature connecting flow to key ecological attributes of the State's turtles, including habitat suitability, reproduction and recruitment, feeding and movement. This paper aims to build understanding of the links between freshwater turtles and flow to inform sustainable water management.

Table 1 Freshwater turtle species of NSW, their conservation status and distribution (DPE, 2018)

Common name	Scientific name	Conservation status	Distribution
Long necked turtle species			
Broad-shelled turtle	*Chelodina expansa*	Least concern	Occurs at lower altitudes in the Murray-Darling River system.
Eastern long-necked turtle	*Chelodina longicollis*	Least concern	Widespread throughout NSW except for the highest parts of the Alps.
Short necked turtle species			
Bellinger River turtle	*Myuchelys georgesi*	NSW: critically endangered; Commonwealth: critically endangered	Occurs only in the Bellinger River system on the NSW mid-north coast.
Bell's turtle, Western saw-shelled turtle	*Myuchelys bellii*	NSW: endangered; Commonwealth: vulnerable	Occurs in northern NSW and Queensland, in the upper reaches of the Border Rivers, Gwydir and Namoi river systems.

[1] https://legislation.nsw.gov.au/view/whole/html/inforce/current/act-2000-092

Common name	Scientific name	Conservation status	Distribution
Eastern saw-shelled turtle	*Myuchelys latisternum*	Least concern	Naturally occurs in rivers of the NSW north coast and hinterland as far south as the Richmond River system, and in Queensland and the Northern Territory. The species has also been introduced to the Sydney metropolitan area.
Manning River turtle	*Myuchelys purvisi*	NSW: endangered	Occurs only in the Manning River and its tributaries on the mid-north coast of NSW.
Murray River turtle	*Emydura macquarii*	Least concern	Occurs in all but the coldest parts of the Murray-Darling River system, and in coastal NSW rivers, from the Queensland border to the Sydney region.

Freshwater turtles and flow relationships

Habitat suitability

Habitat preference

New South Wales' seven native species of freshwater turtle occupy a variety of habitats with diverse flow conditions, including fast flowing rivers, pools of varying depths, wetlands and floodplains. Habitat selection is driven by factors including access to food, refuge from predators, and regulation of body temperature (Blamires & Spencer, 2013; Chessman, 2015). The known habitat preferences of each species are outlined below:

Emydura macquarii

The Murray-River turtle, *E. macquarii*, is known to occupy a range of river habitats, including river channels, backwaters, anabranches, ponds, lagoons, lakes and artificial storages (Chessman, 1988; Singh, 2018; Van Dyke et al., 2019). Chessman's (1988) study of habitat preference of freshwater turtles on the Murray River floodplain reported greater numbers of *E. macquarii* in faster, deeper and clearer water within or close to the main river channel. It was not recorded in any water source less than two metres deep indicating a preference for deeper water. Ocock et al.'s (2018) study of critical turtle habitat across the lower Murrumbidgee floodplain reported similar results, with distribution of *E. macquarii* centred on frequently inundated wetlands close to the river.

Chelodina longicollis

Of the seven freshwater species in NSW, the eastern long-necked turtle, *C. longicollis*, is most strongly associated with temporary water bodies and habitat separate from the main river channel (Chessman, 1988; Howard et al., 2011; Van Dyke et al., 2019). Chessman (1988) reported increased abundance of the species on the Murray River floodplain in habitats with lower water depth, transparency, persistence and flow (when compared to other turtle species recorded on the floodplain). However, it is also commonly caught in habitats with deep, clear, flowing waters and Chessman (1988) notes that the low proportion of *C. longicollis* in the main river channel does not necessarily mean that the species avoids these flow conditions. Rather, these results may reflect the preference of *C. longicollis* for habitats with reduced abundance (and competition from) other species.

Chelodina expansa

The broad-shelled turtle, *C. expansa*, commonly occurs in water too turbid to allow underwater observation and it is rarely observed out of water (Bower & Hodges, 2014). As such, there is relatively little known about the species' habitat preferences. Chessman (1988) reported catching *C. expansa* across a range of river habitats including the main channel, backwaters, oxbows, anabranches, ponds and swamps. Bower, Hutchinson, et al. (2012) reported similar results. Chessman (1988) found no significant relationship between abundance and flow and only a weak relationship between abundance and water depth (suggesting neither river flow nor pool depth strongly influence habitat selection). Drivers of habitat selection for *C. expansa* remain unclear (Bower & Hodges, 2014) and the literature does not provide sufficient evidence of a preference for still or flowing, deep or shallow waters.

Myuchelys bellii

The western saw-shelled or Bell's turtle, *M. bellii*, occupies upland, cold flowing streams that contain permanent pools deeper than about 2 m, separated by shallow sections with dry beds or riffles (Chessman, 2015; Fielder et al., 2015). Modelling by Chessman (2015) indicated that it was more abundant in river reaches with greater mean annual flow. This may be because rivers with greater flow tend to have larger, deeper pools which provide refuge habitat. *M. bellii* is also known to hibernate in deeper water (>3 m) over winter (Fielder, 2012). The Bell's turtle does not appear to occupy lentic habitat separate to flowing streams, such as wetlands (Fielder et al., 2015), and most records of the species are from narrow sections of rivers 30-40 m wide (NSW Threatened Species Scientific Committee, 2019; Wells, 2002). The species is known to forage in shallow pool areas and riffles at night (Chessman, 2015; Fielder et al., 2015)

Myuchelys latisternum

Comparatively little information is available on the habitat of the eastern saw-shelled turtle, *M. latisternum*. It is most often found in the headwaters or tributaries of large rivers in creeks, waterholes, lakes and dams (Freeman & Cann, 2014). Freeman & Cann (2014) suggest that abundance and density of the species decreases as the waterway increases in size and flow, suggesting a preference for slower flowing waters. *M. latisternum* has also been observed in shallow, small sections of streams at night, suggesting it may be dependent on riffles for night foraging (Chessman, 2020, pers. Comm., 3 October).

Myuchelys purvisi & Myuchelys georgesi

The Manning River turtle, *M. purvisi*, and the Bellinger River turtle *M. georgesi* are very similar, so information on habitat, reproduction and ecology can be inferred to be alike (Cogger, 2018; NSW Threatened Species Scientific Committee, 2017). *M. purvisi* is found only in the Manning River and its tributaries on NSW's mid-north coast, in clear, continuously fast-flowing rivers (Wells, 2002). The species occupies pools two or more metres deep during daytime and has been observed in shallower water at night (Chessman, 2020, pers. Comm., 3 October; Wells, 2002).

M. georgesi is also only found on the State's mid-north coast in the Bellinger River catchment. Blamires and Spencer (2013) suggest that adults select moderately deep to deep (>2 m) waterholes. Similarly, Spencer (2007) reported more captures of *M. georgesi* in deep water (>3 m). Modelling by Blamires and Spencer (2013) showed that water-hole depth influences the survival of adult *M. georgesi*. The survivorship of juveniles and hatchlings also increased in moderate to deep water holes devoid of catfish predators. Based on the nocturnal foraging behaviour of *M. purvisi*, it can be inferred that *M. georgesi* utilises riffle habitat at night.

Flow-mediated changes to habitat suitability

Changes in flow may affect the suitability and availability of the preferred habitats of these freshwater turtle species. In addition to changing water depth, flow velocity, volume, and total wetted area (and subsequently reducing habitat availability), altered flow regimes may also affect water quality parameters such as turbidity, dissolved oxygen content and temperature (Rolls et al., 2012). The effects of flow-mediated changes to habitat suitability are likely to vary between species. For example, different species have varying capacities to deal with the reduction of suitable habitat associated with drying of water courses during periods of no or low flow – the frequency and duration of which can increase due to river extraction (Boulton, 2003). Chessman (1984a) demonstrated a high rate of evaporative water loss in both *C. expansa* and *E. macquarii* under hot, dry conditions. As such, both species are vulnerable to water body drying [*E. macquarii* often suffers mass mortality events when semi-permanent water bodies dry in severe drought (e.g. Timms & McDougall, 2006)]. In contrast, Chessman (1984a) reported relatively low rates of evaporative water loss in *C. longicollis* and the species is also capable of aestivation. It is therefore better placed to survive prolonged dry conditions.

Species that inhabit riffles may also be particularly impacted by increasing duration and frequency of low flows as riffle habitat typically dries first when flow declines (Bond et al., 2008). In addition to reducing the availability of this habitat type, a reduction in riffle area may have dietary impacts for turtles known to forage in riffles due to a decline in prey species dependent on fast flowing water, such as riffle-dwelling macroinvertebrates (Bond et al., 2008). *M. latisternum*, *M. belli, M. purvisi* and by inference *M. georgesi* are known to occupy riffle habitat at night and so are likely to be most affected by a reduction in this habitat type (Chessman, 2015; Chessman, 2020, pers. Comm., 3 October; Fielder et al., 2015; Wells, 2002).

Many of Australia's freshwater turtle species, including *M. belli, M. georgesi* and *M. latisternum,* respire bimodally, using cloacal respiration as well as normal respiration to minimise surfacing frequency and extend dive duration (Cameron, 2017; Cann et al., 2015; Fielder, 2012; King & Heatwole, 1994). However, the effectiveness of aquatic respiration in bimodally respiring turtles is limited by environmental conditions including water temperature, dissolved oxygen content, sedimentation and flows, all of which are adversely affected by hydrological alteration associated with extraction and regulation (Gordos et al., 2007; Priest & Franklin, 2002; Rolls et al., 2012; Schaffer et al., 2015). Increased frequency and duration of low flows is associated with reduced dissolved oxygen, increased sedimentation and decreased flow velocity (Rolls et al., 2012). Under anoxic (very low oxygen) conditions, the average dive duration of the bimodally respiring, Queensland species *Rheodytes leukops* more than halved compared to turtles under normal oxygen conditions (Priest & Franklin, 2002). Increased sedimentation significantly reduced the dive duration of *Elseya irwini* – also endemic to Queensland (Schaffer et al., 2015) – and Gordos et al. (2004) associated decreasing water velocity with increased surfacing frequency in *R. leukops*. These findings suggest that changes in habitat suitability related to altered flow regimes are likely to affect cloacal respiration in NSW's bimodally respiring *Myuchelys* species. The impacts of reduced diving duration and increased surfacing frequency may include reduced metabolic efficiency and increased exposure to predators (Clark, 2008; Gordos et al., 2004).

Finally, regulation and extraction may affect habitat suitability for freshwater turtles through changes to water temperature. As ectotherms (cold-blooded animals), the physiological performance of turtles is largely influenced by the temperature of their environment (Bulté & Blouin-Demers, 2009). As such, we can expect changes in water temperature to impact the behaviour and physiology of freshwater turtles. Reduced flow is associated with an increased range of water temperature – higher maximums and lower minimums (Rolls et al., 2012). Regulating storages like dams and weirs also impact water temperature. Cold water pollution commonly occurs downstream of large dams due to thermal stratification within the dam, coupled with the release of the lower cold water layer through outlets located towards the base of the wall (NSW Cold Water Pollution Interagency Group, 2012). Singh (2018) used radiotracking to monitor *E. macquarii* downstream of the cold-water-releasing Hume Dam on the upper Murray River. During spring, Singh reported reduced activity and basking behaviour in *E. macquarii* inhabiting an anabranch affected by cold water pollution compared to individuals in an adjacent floodplain lagoon. Singh suggests that *E. macquarii* may have been responding to artificially reduced water temperatures by extending their overwintering period (marked by reduced metabolism and activity) into spring. By delaying the commencement of activity until later in spring, turtles affected by cold-water pollution face reduced foraging opportunities (Singh, 2018), which may have secondary implications for growth, body condition, reproduction and survival.

The loss of available, suitable turtle habitat presents a significant risk to NSW's freshwater turtles. In addition to the effects of altered habitat suitability outlined above, changes to flow regimes due to river extraction and regulation may specifically impact turtle reproduction and recruitment, food resources and movement. The following sections outline the known impacts of increased and reduced flows, regulating infrastructure, and flow-mediated changes in water quality and connectivity on these key ecological attributes.

Reproduction and recruitment

Dry conditions and high flows can both affect freshwater turtle reproduction and recruitment via several mechanisms, including nest flooding, nest imprisonment and changes in food availability. The effects of flood or extended dry conditions on reproduction and recruitment can significantly impact the survival of turtle populations, given turtles are long-lived, mature slowly and have low fecundity, egg and hatchling survival (Cann, 1998). Consequently, turtles cannot quickly re-establish their populations following mass mortality events (Howard et al., 2011) and may be more vulnerable to the effects of altered flow regimes than other freshwater organisms.

Effects of extended low flows

Extraction of river water can increase the frequency and duration of low flows and drying events, creating artificial droughts (Boulton, 2003). Increased frequency and duration of dry conditions can affect both reproduction and recruitment of freshwater turtles. Firstly, drought may lead to a fall in reproduction. Studies by Kennett and Georges (1990) in Jervis Bay, NSW found that reproduction ceased almost entirely in *C. longicollis* occupying refuge habitat during drought. The study also reported reduced rates of growth and poorer body condition in these populations. Kennett and Georges (1990) note that a delay in growth due to increased intraspecific competition for food in refuge habitat can cause a sharp decline in reproductive output as observed at Jervis Bay. Howard et al.'s (2011) study of *C. longicollis, E. macquarii* and *C. expansa* in Barmah-Millewa Forest found similar results. The study compared nesting activity in 2009-10 during drought and after flooding in 2010-11. A total of 17 nests were recorded following the floods but no evidence of nesting activity by any species was found during the drought year. Howard et al. (2011) attributed the increase in reproductive effort in 2010-11 to improved body condition following the breaking of the drought.

Drought can also lead to a fall in turtle recruitment. Freshwater turtles nest terrestrially, digging a hole in the ground before laying eggs (DPE, 2018). If soil conditions are too dry, turtles may abandon nesting sites and return to the water without laying eggs (Goode & Russell, 1968). Dry soil can also prevent hatchlings from exiting the nest, resulting in death (Chessman, 2018). Chessman (2018) monitored nests of the eastern long-necked turtle, *C. longicollis,* for up to a year after nest construction in the La Trobe Valley, Victoria. Turtles emerged from only 5% of nests and significant numbers of dead hatchlings were apparent in the nests. It is likely that the hatchlings were imprisoned in the nest by dry, hard soil. Similarly, Chessman (2011) sampled turtle populations in the Murray River in 1976-82 following a wet period and in 2009-11 at the end of the Millennium Drought. A significantly reduced proportion of juvenile *C. longicollis* and *E. macquarii* were caught in 2009-11, indicating a fall in recruitment which could have been caused by imprisonment in the nest by dry soil.

The incidence of hatchling nest imprisonment may increase with increased duration of low or no flows and subsequently cause reduced rates of recruitment. However, while low flows may contribute to the hardening of soil and subsequently nest imprisonment, it must be noted that nest imprisonment is mainly related to low rainfall (Chapman 2020, pers. Comm., 3 October). Periods of low flow typically coincide with periods of low rainfall and so the two factors may be conflated.

Effects of high flows and flow regulating infrastructure

Like extended dry conditions, high flows can also impact freshwater turtle reproduction and recruitment. Flooding may inhibit reproduction in female turtles of some species. In March 2001, the Bellinger River turtle, *M. georgesi*, was affected by major floods in the Bellinger River catchment (Spencer et al., 2007). Sampling of the species in October – November 2001, eight months after the floods, indicated that reproduction did not occur in the catchment, with no gravid females captured (Spencer et al., 2007). This reduction in reproduction may have been linked to decreased availability of food, as the floods removed much of the upper river aquatic vegetation (Spencer et al., 2007).

High flows may also lead to reduced recruitment due to nest inundation. Submersion of nests for longer than a few hours can be lethal, causing the embryos to suffocate (Booth, 2010). Kennett et al. (1993) reported a 100% mortality rate for freshly laid *C. longicollis* eggs following 1 week of inundation. Similarly, Hollier (2012) documented 100% mortality of *Emydura macquarii kreftii* (a subspecies of *E. macquarii*) following inundation for longer than half an hour. Some species of freshwater turtles may have developed nesting strategies to reduce the risk of nest inundation. For example, the broad-shelled turtle, *C. expansa*, typically nests uphill, 30-300 m from the water's edge (Booth, 2010). Booth (2010) suggests that given the prolonged incubation period of *C. expansa* eggs, nesting uphill far from the water's edge may be a strategy to minimise the risk of nest flooding. As such, species that nest close to the water's edge may be more susceptible to the risk of nest flooding.

The creation of artificial impoundments by regulatory infrastructure like dams and weirs may increase the risk of nest inundation (McDougall et al., 2015). McDougall et al. (2015) note that nests laid within storage areas face additional risk of inundation. If nests are laid within a storage that has been drawn down for consumptive use, they are more likely to be inundated if inflows occur as the storage will fill to a higher level than a flowing river would because the flows are captured. Increasing the storage level of reservoirs during turtle nesting season has been shown to reduce water level rise during the clutch incubation period of *Elseya albagula* (a freshwater turtle endemic to south-eastern Queensland), reducing the likelihood of nest inundation (McDougall et al., 2015). Nests downstream of artificial impoundments may also be at risk of inundation when water is released from storages as the volume and timing of water releases from a dam are likely to differ from natural flows (Richter & Thomas, 2007). It is important that water releases are carefully managed to avoid the inundation of nesting banks during the incubation period (Commonwealth of Australia, 2017). All NSW species of freshwater turtle nest terrestrially (DPE, 2018), meaning all may be vulnerable to increased risk of nest flooding due to regulating infrastructure. Further analysis of turtle nesting behaviour could provide insight into the species likely to be most at risk.

Both dry and flooding conditions as well as river infrastructure are known to affect freshwater turtle reproduction and recruitment via several mechanisms, including nest flooding and imprisonment, and alterations to food supply. Given freshwater turtles have low fecundity, egg and hatchling survival (Cann, 1998), it is critical that water managers consider the effects of changed flow regimes on turtle reproduction and recruitment.

Food resources

Access to food resources is a critical factor influencing turtle distribution, abundance, habitat selection, body condition and survival. As indicated above, reduced access to food can also affect turtle reproduction. The literature suggests that extended low or high flows, flow-mediated changes in water quality and regulating infrastructure may all impact the access of freshwater turtles in NSW to food resources.

Effects of high or extended low flows

Australian studies have reported varied effects of flooding and high flows on freshwater turtles' access to food. Impacts are likely to vary between species. Flooding in the Bellinger River catchment in 2001 removed a significant amount of upper river aquatic vegetation (Spencer et al., 2007). In some pools, 100% of plant beds were removed. It can be inferred that the removal of vegetation would have direct dietary consequences for omnivorous species. Dietary analysis revealed that the guts of five *M. georgesi* were empty following the flood [however, empty guts are not uncommon (Chessman 2020, pers. Comm., 3 October) so this result may not be evidence of reduced feeding following the flood].

In contrast, flooding of Barmah-Millewa Forest, in 2010-11 resulted in improved body condition of *E. macquarii* when compared to during drought (Howard et al., 2011). The flooding resulted in a significant blackwater event (King et al., 2012). Extremely low levels of dissolved oxygen reduced the abundance of native fish and led to high numbers of dead or dying shrimp and yabbies, likely affecting the availability of food for carnivorous turtle species such as *C. expansa* and *C. longicollis* (Howard et al., 2011). In February 2010, Howard et al. (2011) collected both species as well as *E. macquarii* in relatively high numbers in a permanent wetland before the blackwater event (Howard et al., 2011). In February 2011, only *E. macquarii* were captured at the site. As the only omnivorous species of the three, *E. macquarii* are not reliant on fish, yabbies or other invertebrates that may have perished during the blackwater event. As such, *E. macquarii* could benefit from reduced competition for food by other freshwater turtle species. *C. expansa* and *C. longicollis* may have migrated to unaffected sections of the forest to avoid starvation or perished, though no evidence of turtle mortality was found during the study.

During periods of high flow, *C. longicollis* preferentially inhabit ephemeral creeks, floodplains and wetlands (these sites may also be fed by rainfall and local runoff instead of or in addition to overbank flooding) (Chessman, 2011; Howard et al., 2016; Howard et al., 2011; Kennett & Georges, 1990; Roe & Georges, 2008). By inhabiting these temporary habitats, *C. longicollis* benefit from increased productivity and reduced competition for food (Chessman, 1984, 1988; Georges et al., 1986). Howard et al. (2011) found that in Barmah-Millewa Forest, body condition improved by up to 8.9% in individuals collected in ephemeral habitat during flooding compared to those collected in permanent, refuge habitat during drought. Howard et al. (2016) reported similar improvements in the body condition of *C. longicollis* inhabiting temporary floodplain habitats following environmental flows. In contrast, *C. longicollis* can face reduced access to food resources when occupying permanent wetlands during drought. Kennett & Georges (1990) observed a significant decline in growth and body condition of eastern long-necked turtles occupying permanent dune lakes in Jervis Bay, NSW, during dry conditions due to high population densities and low productivity in these lakes.

Kennett and Georges' (1990) findings demonstrate that, like floods, extended low flows during drought periods can impact access to food resources. Again, the impacts are likely to vary by species. Chessman (2011) compared turtle populations in the Murray River in 1976-82 following a wet period and in 2009-11 following drought. He found reduced abundance of *C. longicollis* and *E. macquarii* following the drought but no significant change in *C. expansa*. Chessman concluded that the species likely fared better as it is more adept at feeding on alternative food sources (including crustaceans and fast swimming bugs) that are abundant in the main channel of the Murray River. *C. expansa* therefore appears to be better placed than *C. longicollis or E. macquarii* to retain access to food resources and survive in permanent waters during prolonged drought.

These studies demonstrate that both high flows and extended low flows can impact access to food resources by freshwater turtles, with implications for turtle distribution, body condition and survival. Some NSW species may be better placed to withstand these impacts than others.

Effects of flow-mediated changes in water quality

Altered flow regimes are linked to increased sedimentation and turbidity (Gippel & Blackham, 2002) with potential consequences for freshwater turtles. Increased sedimentation may smother the stream bed, restricting growth of aquatic macrophytes and filling interstitial spaces, which both provide habitat for macroinvertebrates (Allanson & Georges, 1999). Benthic macroinvertebrates make up a high proportion of the diet of several NSW turtle species (Allanson & Georges, 1999; Spencer et al., 2014). Consequently, the effects of increased sedimentation on macroinvertebrate assemblages are likely to impact the composition and abundance of food available to turtles.

Short-necked turtles, including NSW species of both *Emydura* and *Myuchelys*, lack the specialised behaviour and morphological adaptations of long-necked species to catch fast-moving prey, especially in highly turbid water (Allanson & Georges, 1999; Spencer et al., 2014). Terrestrial invertebrates that fall on the surface of the water and filamentous algae become increasingly important in the diets of species inhabiting turbid water (Spencer et al., 2014). However, the growth of filamentous algae is also limited by water clarity (Liboriussen & Jeppesen, 2003). Petrov et al. (2018) compared the diets of freshwater turtles across Murray River habitats of varying water clarity. *E. macquarii* inhabiting the most turbid sites had high rates of empty stomachs and smaller proportions of filamentous green algae in the stomachs. In contrast, turtles at sites with relatively clear water usually had food in their stomachs, including high volumes of algae.

These studies demonstrate that in addition to directly impacting access to food resources, changes in river flow can mediate secondary impacts on feeding via changes in water quality.

Effects of flow regulating infrastructure

The construction of infrastructure to manage flows, such as dams and weirs, may also have dietary impacts for freshwater turtles, including by changing river reaches to impoundments which may benefit some turtle species but disadvantage others (Tucker et al., 2012). Tucker et al. (2012) compared the diets of three turtle species (the largely carnivorous *M. latisternum*, an omnivorous Queensland species and an herbivorous Queensland species) from free-flowing rivers and those impounded by dams or weirs in south-eastern Queensland. The diets of all three turtle species were markedly different between impounded sites and river sites and relative to river samples, there was a net decrease in dietary diversity and breadth in impoundment sites. *M. latisternum* in impoundments consumed fewer aquatic invertebrates than in riverine habitats and were more likely to demonstrate scavenging behaviour. Importantly, Tucker et al. (2012) noted that for the most omnivorous species, the kinds of food consumed differed between impoundments and rivers but differences in the amount of food consumed were minor.

This demonstrates that turtles with narrow dietary preferences are likely to be most affected by changes in food availability due to regulation and changes in flow.

Movement

Freshwater turtles can travel extensively within river channels and some species also undertake migration overland. For freshwater turtles, movement provides critical access to nesting, foraging and refuge habitat, food resources, and mates (Baggiano, 2012; Cameron, 2017; Chessman, 1988; Espinoza et al., 2018; Ocock et al., 2018). However, movement by freshwater turtles depends strongly on access to water and connectivity between suitable habitat. Increased use of river water and regulation by dams and weirs has reduced connectivity along the length of rivers (longitudinal connectivity) and between main river channels and adjacent floodplains and wetlands (lateral connectivity) (Murray-Darling Basin Authority (MDBA), 2018). By limiting opportunities for movement, reductions in connectivity may impact the longevity of NSW’s freshwater turtle populations.

Effects of changes in longitudinal connectivity

Most species of freshwater turtle in NSW rarely travel terrestrially, meaning dispersal primarily occurs within water courses (Baggiano, 2012). Some species in particular are known to travel long distances within river channels. Bower, Hutchinson, et al. (2012) used radiotelemetry to monitor the movement and activity of the broad-shelled turtle, *C. expansa*, in the Murray River. Over the course of the study (roughly two and a half years), male turtles travelled up to 25 km within the main channel, its backwaters and connected swamps and inlets. A second study in the Murray River used radio tracking to track in-stream movements of up to eight kilometres within a year by the Murray River turtle, *E. macquarii* (Singh, 2018). Male Bell's turtles, *M. belli*, have also been reported travelling distances of over 40 km (Local Land Services, 2018).

Over the past 150 years, hundreds of dams and weirs have been constructed in NSW and throughout Australia (Cameron, 2017; MDBA, 2018). This infrastructure reduces longitudinal connectivity, fragments ecosystems and creates barriers for upstream and downstream movement (Baggiano, 2012). The effects of regulation on longitudinal connectivity become more prominent during periods of low flow and may be exacerbated by water extraction from rivers (Baggiano, 2012; MDBA, 2018). Reductions in river connectivity have implications for population connectivity between groups of the same species separated by fragmented ecosystems (metapopulations). Reduced connectivity between metapopulations limits breeding potential and stops the replenishment of populations which may have suffered high rates of mortality (such as by fox predation) (Cameron, 2017). Cameron (2017) studied the impact of man-made barriers on movement and extinction risk for freshwater turtles in the Murray-Darling Basin. She demonstrated that in highly connected habitat between dams and impoundments, turtle populations could sustain relatively high rates of mortality. With reduced connectivity between metapopulations, the likelihood of extinction rose.

Reduced population connectivity limits gene flow (Cameron, 2017). Gene flow between isolated populations is critical to ensure the continued survival of the species (Cameron, 2017). Baggiano (2012) examined gene flow in freshwater turtles in the Murray-Darling Basin. The study reported breaks in gene flow in *E. macquarii* associated with structural features in the river network such as dams, suggesting that the species may be restricted by within-channel barriers to movement. For species that cannot move (long distances) terrestrially or through man-made barriers, reduced longitudinal connectivity reduces population and genetic connectivity, increasing the risk of extinction (Baggiano, 2012; Cameron, 2017).

Effects of changes in lateral connectivity

Given most freshwater turtles species in NSW are primarily aquatic, terrestrial movements are likely to be small (Baggiano, 2012). The Murray River turtle, *E. macquarii*, has been recorded travelling up to 534 m overland (Singh, 2018). However, the eastern long-necked turtle, *C. longicollis*, is the species most likely to undertake terrestrial migrations. The species' capacity to aestivate and withstand desiccation enables it to travel overland and terrestrial migrations of up to five kilometres have been recorded (Chessman, 1983, 1984; Roe, 2007). Migration allows *C. longicollis* to take advantage of ephemeral wetlands which it preferentially occupies during high flow (or high rainfall) periods (Chessman, 2011; Howard et al., 2016; Kennett & Georges, 1990; Roe & Georges, 2008). These temporary habitats provide the species with health, food and reproductive benefits (see above) but overland migration also exposes turtles to increased risk of predation and road traffic (Chessman, 2011; Santori et al., 2018).

Migration to ephemeral habitats also places *C. longicollis* at risk when temporary wetlands dry during periods of low flow or rainfall. During dry conditions, the species will either aestivate on land or return to permanent wetlands. Studies have shown that individuals will selectively respond to wetland drying based on the distance to the nearest permanent wetland (Roe, 2007; Roe & Georges, 2008). In Booderee National Park, NSW, 100% of turtles moved to permanent wetlands when separated by a distance of less than 100 m (Roe & Georges, 2008). At 1400-1500 m, 67% of turtles remained on land, aestivating in or near the drying wetland. This demonstrates that the response of *C. longicollis* to drying ephemeral wetlands – to aestivate or to travel – is influenced by the level of connectivity between these sites and permanent waterbodies.

Individuals that respond to drying wetlands by aestivating in place still require access to critical refuge habitats during extended drought as the length of time for which *C. longicollis* can aestivate is limited (Roe et al., 2008). In Booderee National Park, some *C. longicollis* survived terrestrial aestivation for up to 480 consecutive days while awaiting reflooding (Roe & Georges, 2008). However, a larger proportion (45%) of those that remained on land died compared to those that returned to permanent water (18%). The duration of aestivation is limited by the exhaustion of energy reserves or dehydration (Roe et al., 2008). *C. longicollis* cannot feed out of water so long-term maintenance of energy reserves requires access to water bodies (Chessman, 2011). With decreasing connectivity, opportunities for movement between waterbodies become more limited. As a result, reductions in lateral connectivity may lead to increased mortality of *C. longicollis*.

The aquatic and terrestrial migratory habits of freshwater turtles highlight the importance of connectivity along the length of a river and between the main channel and floodplain for turtle feeding, reproduction and survival during drought. Therefore, disruptions to connectivity as a result of water use in NSW and infrastructure such as dams and weirs have the potential to negatively impact the State's freshwater turtle populations.

Potential impacts of water use and regulation on freshwater turtles

There is substantial evidence that key ecological attributes (habitat suitability, reproduction, recruitment, feeding and movement) of NSW's freshwater turtle species are linked to flow. Given that the extraction of water and river regulation has altered the natural flow regime of the State's rivers (affecting flow volumes, variability, connectivity and water quality) (MDBA, 2018; Rolls et al., 2012), it can be inferred that water use and regulation impact freshwater turtles. Some species may be more vulnerable than others.

As summarised in Figure 2, the primary mechanisms through which water extraction and regulation may impact freshwater turtles are:

1. **Extraction from pools may reduce pool volume and depth, reducing refuge habitat**

   Water extraction from river pools may lead to a reduction in pool volume and depth. This limits the availability of refuge habitat for freshwater turtles. Species that prefer to occupy deep pools (*M. bellii, M. georgesi*, *M. purvisi* and *M. latisternum,)* are likely to be most affected. Water is extracted from pools for stock and domestic (S&D), basic landholder rights (BLR) and licenced water use. To a lesser degree, extraction from running river waters may also reduce pool volume and depth over time due to evaporation and the cessation of flows into pools.

2. **Extraction from running river waters during low flows may reduce riffle and shallow pool edge foraging habitat**

   During periods of low flow, water extraction from running waters (and pools) for BLR, S&D and licenced water use reduces the availability of riffle and shallow pool edge habitat. These habitats are typically the first to dry when flows cease. *M. bellii*, *M. latisternum, M. purvisi* and, by inference, *M. georgesi* forage nocturnally in riffles and/or shallow pool edge habitat. These species may be affected through reduced habitat availability and the removal of riffle-dependent prey species.

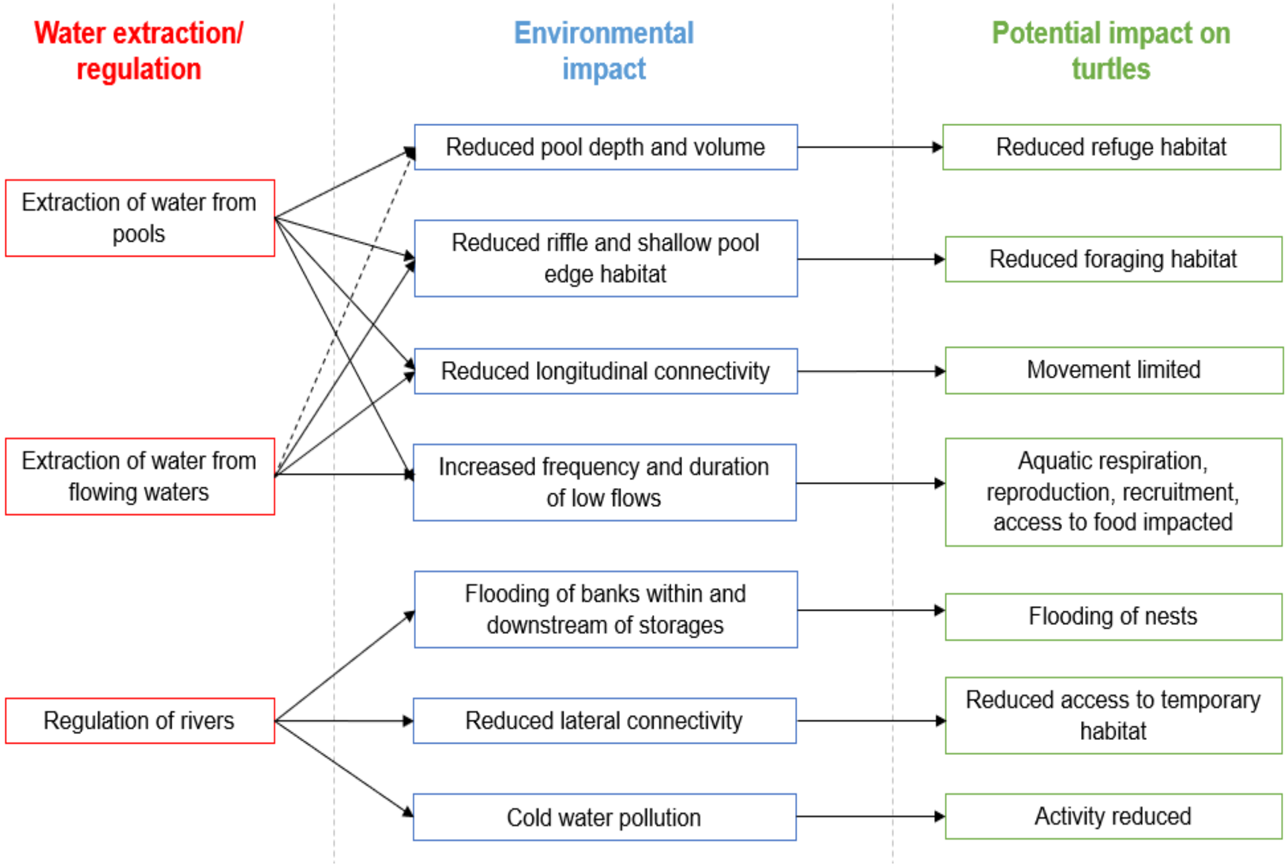

Figure 2 Conceptual model – potential impacts of water use and regulation on freshwater turtles

3. **Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting aquatic respiration, reproduction and recruitment, and access to food resources**

   Water extraction from rivers (for licenced take, BLR and S&D use) increases the frequency and duration of low flows. Low flows are associated with reduced flow volume, flow velocity and dissolved oxygen and increased sedimentation. The latter three factors are known to impact aquatic respiration in freshwater turtles, with NSW's bimodally respiring *Myuchelys* species potentially affected. Increased frequency and duration of low flows may also impact freshwater turtle feeding, with reduced access to food resources during extended low flows being linked to falls in freshwater turtle abundance, body condition, growth, reproduction and recruitment.

4. **Extraction from running river waters and regulating infrastructure may limit turtle movement by reducing river connectivity**

   Licenced water take from running river waters (and pools) and, to a lesser degree, extraction for BLR and S&D use can reduce longitudinal connectivity along the length of a river system. The effects of extraction are likely to be most severe during periods of low flow. Water regulating infrastructure such as dams and weirs also create barriers to longitudinal connectivity. Multiple NSW species of freshwater turtle have been recorded making movements of several kilometres or more. These movements are impeded by reduced longitudinal connectivity, potentially affecting population connectivity and access to food resources, mates and refugia. Species that move primarily through water and make minimal movements overland (i.e. all species but *C. longicollis*) are most at risk.

   River regulation reduces the frequency and volume of moderate to high flow events. This limits lateral connectivity between the main river channel and its floodplains, reducing access to temporary habitat. The eastern long-necked turtle, *C. longicollis*, preferentially occupies temporary floodplain habitat, where it benefits from reduced competition, increased productivity, improved body condition and increased reproduction. Reduced lateral connectivity restricts access to these benefits and can also increase mortality if turtles become stranded in drying ephemeral habitat.

5. **Regulating infrastructure may increase the risk of nest inundation, impact access to food resources, impact water temperatures and change turtle behaviour**

   In addition to reducing connectivity, the regulation of rivers for irrigation and water supply can increase the risk of nest flooding within and downstream of storages. This has significant implications for freshwater turtle recruitment, with a 100% mortality rate reported for *C. longicollis* and *E. macquarii* eggs subject to inundation (the eggs of other species are likely to be similarly affected). Regulating infrastructure also causes downstream cold-water pollution. Freshwater turtles in water sources affected by cold water pollution demonstrate changes in behaviour, including delayed activity which can reduce foraging opportunities. Changes in feeding behaviour and food resources have also been reported in freshwater turtles within artificial impoundments.

Conclusions and next steps

To protect the State's freshwater turtle species and the ecological functions they deliver (and in so doing, meet the objectives of the *Water Management Act 2000*), it is critical that water managers understand how changes in river flow due to water extraction and regulation may impact turtle ecology. The literature provides substantial evidence that river flow is linked to freshwater turtle habitat suitability, reproduction, recruitment, access to food resources and movement (summarised in Table 2). Changes in river flow due to water extraction (from both pools and running water, for stock and domestic, basic landholder rights and licenced water use) and the regulation of rivers for irrigation and town water supply are therefore likely to impact freshwater turtles. The severity of these impacts is likely to vary by species, with endangered turtles – *M. belli, M. purvisi* and *M. georgesi* – potentially most at risk.

However, there is still uncertainty about the direct causal links between flow and turtle ecological attributes. Much of the literature linking NSW species to flow is limited to specific flood or drought events. The reported impacts of these events on turtles may be conflated with factors other than flow, such as rainfall. For the most part, freshwater turtle management programs in NSW (Appendix A) do not focus on the impacts of changes in river flow due to water use and regulation. As such, this is a major knowledge gap that requires direct evaluation to ensure the appropriate management of flows to protect freshwater turtles.

A dedicated monitoring, evaluation and reporting (MER) program focused on freshwater turtles in NSW is recommended. In the first instance, however, more research is needed to determine where and for which species focused MER is needed. We recommend:

a) Surveying of water sources to provide estimates of species abundance and occupancy, improving the availability of turtle distribution data. eDNA could provide an alternative technique to supplement the use of traps, nets, snorkelling surveys and BRUVs.

b) Assessment of the usage of shallow pool edge and riffle habitat by select species using radio-tagging. This assessment should focus on water sources where both water extraction and these species are known to occur.

c) Investigation of the likelihood of nest flooding within and downstream of artificial storages, considering historical flow records, species distribution and known nesting behaviour.

d) Further research of the habitat preference, food resources, reproduction, recruitment and movement of all species is still required. Specifically endangered *Myuchelys* species (which are most vulnerable to the impacts of changes in river flow) and *M. latisternum* (for which comparatively little information was available to link the species to flow).

e) Seeking opportunities to collaborate with other NSW freshwater turtle management programs (such as the Saving our Species program) and research institutions to better understand turtle-flow relationships and enable the better management of flows to protect freshwater turtles in NSW.

Table 2 Summary of known links between flow and key ecological attributes of NSW's freshwater turtle species and potential impacts of water management actions on these species

Turtle species	Evidence of ecological links to flow				Potential impacts of water use and regulation	Reference(s)
	Habitat preference and suitability	Reproduction and recruitment	Food resources	Movement		
Murray River turtle (*Emydura macquarii*)	Versatile but prefer faster, clearer water >2m deep close to the main river channel Activity and basking behaviour reduced by cold water pollution downstream of storages Vulnerable to effects of water course drying	Recruitment reduced following drought No evidence of nesting activity in Barmah-Millewa Forest during 2009-10 drought 100% mortality rate for eggs experimentally inundated > 30 minutes	Blackwater event in Murray River led to improved body condition – linked to reduced competition for food from affected dietary specialists Increased turbidity associated with reduced stomach content; may reduce ability to catch prey Reduced abundance in Murray River following drought – linked to reduced availability of accessible food sources	Short overland movement has been recorded but primarily aquatic movements; aquatic movement up to 8km recorded Movement may be affected by reduced connectivity Breaks in gene flow linked to in-stream barriers to movement	1. Regulating infrastructure and water extraction from running river waters may reduce longitudinal connectivity, affecting aquatic movements 2. Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting reproduction, recruitment, and access to food resources 3. Regulating infrastructure may increase the risk of nest inundation and impact turtle physiology and behaviour through cold water pollution	Allanson & Georges, 1999; Cameron, 2017; Chessman, 1984a, 1988, 2011; Hollier, 2012; Howard et al., 2011; Ocock et al., 2018; Petrov et al., 2018; Singh, 2018; Spencer et al., 2014; Van Dyke et al., 2019
Eastern long-necked turtle (*Chelodina longicollis*)	Versatile but prefers shallower, slower flowing temporary water bodies separate from the main river channel Resistant to effects of water course drying	High rates of nest imprisonment during drought Reproduction significantly reduced in refuge habitat during drought – linked to reduced body condition Recruitment reduced following drought No evidence of nesting activity in Barmah-Millewa Forest during 2009-10 drought 100% mortality rate for eggs experimentally inundated for 1 week	Improved body condition in ephemeral habitats during high flow or high rainfall periods – linked to increased productivity and reduced competition Reduced body condition and growth in permanent refuge habitat during drought Reduced abundance following blackwater event in Murray River – linked to reduced food availability; more vulnerable due to specialised diet Reduced abundance in Murray River following drought – linked to reduced availability of accessible food sources	Can travel overland up to 5km to reach ephemeral habitat Response (move or stay) to drying ephemeral habitat influenced by distance to permanent wetlands Increased mortality when stranded in drying temporary habitats – may increase with decreasing lateral connectivity	1. Regulating infrastructure and water extraction from running river waters may reduce lateral connectivity, reducing access to beneficial temporary habitat and increasing mortality when temporary habitats dry 2. Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting reproduction, recruitment, and access to food resources 3. Regulating infrastructure may increase the risk of nest inundation	Chessman, 1984a, 1988, 2011, 2018; Georges et al., 1986; Howard et al., 2011, 2016; Kennett et al., 1993; Kennett & Georges, 1990; Roe, 2007; Roe et al., 2008; Roe & Georges, 2008; Van Dyke et al., 2019
Broad-shelled turtle (*Chelodina expansa*)	Versatile; no evidence for habitat preference based on water flow, depth Vulnerable to effects of water course drying	No evidence of nesting activity in Barmah-Millewa Forest during 2009-10 drought Nesting far from river channel may be strategy to avoid nest inundation	Ability to access alternative food sources (e.g. fast-swimming bugs) linked to increased resistance to drought Reduced abundance following blackwater event in Murray River – linked to reduced food availability; more vulnerable due to specialised diet	Minimal movement over land; aquatic movements of at least 25km recorded Movement may be affected by reduced connectivity	1. Water extraction from running river waters may reduce longitudinal connectivity, affecting aquatic movements 2. Regulating infrastructure may increase the risk of nest inundation	Booth, 2010; Bower, Hutchinson, et al., 2012; Bower & Hodges, 2014; Chessman, 1984a, 1988, 2015; Howard et al., 2011

Turtle species	Evidence of ecological links to flow				Potential impacts of water use and regulation	Reference(s)
	Habitat preference and suitability	Reproduction and recruitment	Food resources	Movement		
Bell's turtle, Western saw-shelled turtle (*Myuchelys bellii*)	Occupies upland, cold flowing rivers with persistent pools deeper than 2 m Occupies shallow habitat at night – vulnerable to loss of riffle habitat when flow ceases Increased sedimentation, reduced DO and velocity during low flows may affect bimodal respiration	Hatchlings disperse through riffles and rivulets to new pools Hatchlings occupy shallow pool edges with aquatic vegetation Hatchlings can disperse up to 2.8km in the first two weeks of life	Increased turbidity may reduce ability to catch prey	Hatchlings disperse through riffles and rivulets to new pools Hatchlings can disperse up to 2.8km in the first two weeks of life Minimal movement overland; adult aquatic movements of at least 40km recorded Movement may be affected by reduced connectivity	1. Water extraction from pools may reduce pool volume and depth, reducing the availability of refuge habitat 2. Water extraction from running river waters during low flows may reduce the availability of riffle and shallow pool edge foraging habitat 3. Regulating infrastructure and water extraction from running river waters may reduce longitudinal connectivity, affecting aquatic movements 4. Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting aquatic respiration and access to food resources	Fielder, 2012; Fielder et al., 2015, 2015; Gordos et al., 2004; Local Land Services, 2018; NSW Threatened Species Scientific Committee, 2017; Priest & Franklin, 2002; Schaffer et al., 2015; Wells, 2002; Streeting *et al* (in prep)
Eastern saw-shelled turtle (*Myuchelys latisternum*)	Prefers slower flowing water in creeks, waterholes, lakes and dams in headwaters or tributaries of large rivers Occupies shallow habitat at night – vulnerable to loss of riffle habitat when flow ceases Increased sedimentation, reduced DO and velocity during low flows may affect bimodal respiration	*No literature found*	Increased turbidity may reduce ability to catch prey Dietary diversity and breadth reduced in impoundments compared to rivers; more likely to scavenge in impoundments	Minimal movement over land Movement may be affected by reduced connectivity	1. Water extraction from running river waters may reduce the availability of riffle and shallow pool edge foraging habitat 2. Regulating infrastructure and water extraction from running river waters may reduce longitudinal connectivity, affecting aquatic movements 3. Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting aquatic respiration and access to food resources 4. Regulating infrastructure may impact access to food resources	Allanson & Georges, 1999; Chessman, 2020, pers. Comm., 3 October; Freeman & Cann, 2014; Gordos et al., 2004; Priest & Franklin, 2002; Schaffer et al., 2015; Spencer et al., 2014; Tucker et al., 2012
Manning River turtle (*Myuchelys purvisi*)	Found in clear, continuously fast flowing rivers in pools 2 or more metres deep Occupies shallow habitat at night – vulnerable to loss of riffle habitat when flow ceases Increased sedimentation, reduced DO and velocity during low flows may affect bimodal respiration	*No literature found*	Increased turbidity may reduce ability to catch prey	Minimal movement overland Movement may be affected by reduced connectivity	1. Water extraction from pools may reduce pool volume and depth, reducing the availability of refuge habitat 2. Regulating infrastructure and water extraction from running river waters may reduce longitudinal connectivity, affecting aquatic movements 3. Water extraction from running waters may reduce the availability of riffle and shallow pool edge foraging habitat 4. Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting aquatic respiration and access to food resources	Allanson & Georges, 1999; Chessman, 2020, pers. Comm., 3 October; Gordos et al., 2004; Priest & Franklin, 2002; Schaffer et al., 2015; Spencer et al., 2014; Wells, 2002

Turtle species	Evidence of ecological links to flow				Potential impacts of water use and regulation	Reference(s)
	Habitat preference and suitability	Reproduction and recruitment	Food resources	Movement		
Bellinger River turtle (*Myuchelys georgesi*)	Prefers deeper pools (>2m) Inferred to occupy shallow habitat at night – vulnerable to loss of riffle habitat when flow ceases Increased sedimentation, reduced DO and velocity during low flows may affect bimodal respiration	Reproduction reduced by flood – linked to decreased food availability	Removal of aquatic vegetation by flooding linked to reduced stomach content Increased turbidity may reduce ability to catch prey	Minimal movement over land Movement may be affected by reduced connectivity	1. Water extraction from pools may reduce pool volume and depth, reducing the availability of refuge habitat 2. Water extraction from running river waters may reduce longitudinal connectivity, affecting aquatic movements 3. Water extraction from running waters may reduce the availability of riffle and shallow pool edge foraging habitat 4. Extraction from running river waters can increase the frequency and duration of low flows, potentially impacting aquatic respiration and access to food resources	Allanson & Georges, 1999; Blamires & Spencer, 2013; Gordos et al., 2004; Priest & Franklin, 2002; Schaffer et al., 2015; Spencer et al., 2007, 2014

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Appendix I – Current freshwater turtle programs in NSW

Several programs are currently operating in NSW which aim to protect and improve understanding of the State's freshwater turtle species. These projects are primarily focused on protecting endangered species in the wild and through captive breeding programs.

Turtles Forever

Local Land Services NSW operates the Turtles Forever project aimed at protecting the endangered Bell's Turtle, *Myuchelys Belli*. The ten-year program commenced in 2016 and involves several initiatives, including:

- Implementation of field surveys through a mark-recapture program
- Deployment of a detection dog to find and protect turtle nests
- Commencement of three postgraduate research students and their collection of valuable field and laboratory data
- Egg induction and rearing of hatchlings and gave juveniles a head start to release into the wild
- Collaboration with private landholders to protect Bell's Turtle habitat on farms.

The program has delivered positive results, including through annual turtle monitoring at 29 sites across the four main catchments inhabited by the species. In October 2018, it was reported that the monitoring resulted in the recording of measurements and details of 432 Bell's turtles and included multiple recaptures. Two male turtles were reported to travel over 40 km from their original point of capture.

More information on Turtles Forever.

Saving our Species

The NSW Department of Planning and Environment's - Environment, Energy and Science division oversees the Saving our Species program. The State-wide program aims to secure threatened plants and animals in the wild in NSW. Three species of freshwater turtle are targeted by the program – the Bell's turtle, *M. bellii;* the Manning River turtle, *M. purvisi*, and; the Bellinger River turtle, *M. georgesi.*

As part of the Bell's turtle Saving our Species strategy, the department is documenting sites where water is being drawn from turtle habitat and working with property owners to decrease the impacts on riffle and deep-water habitats for daytime and drought refuge. The department is also researching the effects of flooding on habitat quality, food resources, turtle health, reproduction and survival. The strategy is also interested in verifying the usefulness of cost-effective methods of sampling turtles across different habitat types (this may provide an opportunity to use BRUVs).

A priority action for the Manning River turtle Saving our Species strategy is addressing knowledge gaps around habitat loss. The department will liaise with Fisheries to conduct field assessments to determine the highest priorities for remediation of barriers to turtle passage.

The Bellinger River turtle strategy includes actions to better understand the impacts of changes in habitat and resource availability on the species. This involves testing water quality and aquatic biota of the turtle habitat. The main components are annual surveys to monitor population trends, health and growth (led by the department), captive breeding at Taronga Zoo and Symbio Wildlife Park, and monitoring of released, captive bred turtles by the department (Chapman 2020, pers.

Comm., 3 October 2020). The strategy also includes the development of a citizen science project – Bellinger Riverwatch – to collect continuous water quality data.

More information on Saving our Species strategies for the Bell's turtle, Manning River turtle and Bellinger River turtle.

Manning River turtle project, Local Land Services

Hunter Local Land Services is working with the Manning River Turtle Conservation Group, Aussie Ark, the Mid Coast Council, and department's Environment, Energy and Science division to protect the endangered Manning River turtle. Through the Every Bit Counts project, LLS are targeting smaller landholders in priority areas of the mid-upper reaches of the Murray River to identify key habitats and conduct motion-camera monitoring for the presence of pest species.

More information.

https://www.environment.nsw.gov.au/news/rare-turtles-saved-from-shrinking-waterholes

Manning River and Hunter River turtle projects, Aussie Ark

Since 2019 Aussie Ark has led a conservation program to protect the Manning River turtle. A crowd funding campaign enabled the construction of a purpose-built facility containing 10 breeding ponds at the Australian Reptile Park. Aussie Ark also undertake in-situ work including monitoring of wild turtles, restoration of nesting sites and the collection of turtles to be used in the captive breeding program.

In February 2020, Aussie Ark announced a second crowd funding campaign to protect the Hunter River turtle, a subspecies of the Murray River turtle. If successful, funds will be used to construct a second captive breeding facility and continue monitoring and protecting turtles in the wild. In February, Aussie Ark reported working with the NSW Government to collect 20 individuals to be used in the captive breeding program.

More information about the Manning River turtle project and the Hunter River turtle project.

Australian Freshwater Turtle Research Facility, UWS

The University of Western Sydney operates the Australian Freshwater Turtle Research Facility in Richmond, NSW. The facility has indoor aquatic rooms, glasshouse facilities and laboratory facilities that can incubate more than 2000 eggs a season.

The university is undertaking research into hybridisation between the Bellinger River turtle and the Murray River turtle. More information.

The university is also leading the *Saving Murray River turtles from extinction* project. This project involves collaboration between industry partners, indigenous groups, and non-government organisations. The project aims to assess turtle numbers in the Murray River and develop a management plan. It involves genetic testing and a citizen science project – TurtleSAT – which allows members of the public to record sightings of the species. More information.